The wide range front-end electronics for readout amplitude date of the ionization calorimeter

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Abstract

In this paper the set analog converters for the multi channel analog processor is presented. This processor is used in high-energy cosmic-ray experiments involving ionization calorimeter is sited near Alma-Ata at a height of 3340 m above sea level, at the Tien Shan. Also the system front-end electronics with dynamic range 500000 : 1, worked put specialty for research of halo at the ionization calorimeter is cited.

1. Introduction

Experiments with X-ray films and emulsion chambers (XREC) showed that approximately in 50% of interactions of cosmic rays at primary energies $E > 10^{16} eV$ there were observed in X-ray films under lead so called halo - big diffusive dark spots the area of which could be from several square millimeters to several square centimeters [1]. The number of charged particles which created halo could run up to hundreds of millions.

The energy evaluation in halo region is made now indirectly by means of model depending methods. So far as the interactions with halo formation differ greatly from other interactions by many characteristics it is very important to have a direct method of number of particles measuring in halo region. One needs electronics for this purpose with very wide dynamic range - not less than $5 \times 10^5 : 1$.

2. Hardware

2.1. The current - sensitive preamplifier

The simplified diagram of the preamplifier is shown in Fig.1. It is a fast low - noise current - sensitive preamplifier covering 2000 : 1 linear dynamic range with signal-to-noise ratio S/N about $3 - 5$. The current sensitivity is equal to $i_{inmin} = 5{\cdot}10^{-9}A$. The purpose of the preamplifier is current-to-voltage conversion with $0.5V/\mu A$ without integrating the input pulse.

This preamplifier is a transresistance amplifier [2] which provides an output voltage proportional to the input current. The transresistance transfer function of this section is

$$R_F = -V_{out}/i_{in} \approx -R_f/(1 + 1/A\beta) \qquad (1)$$

where $\beta = R_{in}/(R_{in} + R_f)$, A is the open loop dc voltage gain of the OA, Rin is the input resistance of the OA. If $A\beta \gg 1$, then the equation for the transfer function is reduced to:

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$$R_F \cong -R_f \tag{2}$$

Hence, the output voltage is

$$V_{out} = -i_{in} R_f \tag{3}$$

The main contribution to the summary output noises of this preamplifier gives the thermal noise of the feedback resistor when the operational amplifiers with field - effect transistors are used, and provided that $R_{in} \gg R_f, R_g \gg R_f$ and $A \gg R_f/R_g$, where Rg is the internal resistance of the signal source [3]. In this case, the summary output thermal noise for a limited signal band is equal to:

$$\bar{U^2_{Nf}} = 2kTR_f arctg(2\pi f_2 R_f C_f)/\pi C_f R_g + 2kTAarctg(2\pi f_2 R_f C_f)/\pi C_f \tag{4}$$

where k is the Boltzmann's constant, T is the Kelvin's temperature, C_f is the feedback capacitor, f_2 is the upper frequency of a band $\Delta F = f_2 - f_1$ (let $f_2 \gg f_1$). The ratio R_f/R_g in (3) determines the contribution of Rg thermal noises, and A - the contribution of R_f thermal noises. If assumes that $A \gg R_f/R_g$, then the equation (3) is reduced to:

$$\bar{U^2_{Nf}} = 2kTAarctg(2\pi f_2 R_f C_f)/\pi C_f \tag{5}$$

The signal-to-noise ratio of the preamplifier is

$$S/N = i_{in} R_f^{1/2}/(4AkT\Delta F)^{1/2} \tag{6}$$

2.2. The simple charge - to - time converter

The principal circuit of the converter is shown in Fig.2. The circuit of the converter is similar to the well-known up/down integrator but is differed from the latter because of, firstly, the time interval of the first cycle of integration is not fixed and is set up with an input pulse duration and, secondly, the circuit is without use of analogous switching elements [4,5].

The basic operation of the converter can be described, mainly, as follows. Let us consider the operation of the circuit for the positive input signals $V_{in}(t)$. In this case the reference voltage V_0 must be negative. In order to avoid a saturation of the operational amplifier "$O-1$" it is necessary that $V_z \leq V_{out.m}$, where V_z is breakdown voltage of a Zener's diode "DZ", and $V_{out.m}$ a means maximum output of the amplifier "$O-1$". An input current i_{in} is integrated during the first cycle, $t_{up} = t_2 - t_1$, together with the reference current io (at condition that io ¡¡ iin) and the output voltage V_{out} of the integrator is decreased from V_z to V_m . The value

$$V_m \approx \frac{-1}{R1C1} \int_{t_1}^{t_2} V_{in}(t)dt \tag{7}$$

is proportional to input charge. In the second cycle, $t_{down} = (t_3 - t_2)$, after integration of an input signal there is a linear discharge of the capacitor $C1$ due to an integration of the reference constant current $i_o = V_o/(R_2 + R_3)$. This discharge continues till the output voltage of the integrator is equal to the initial level V_z . The time interval T of the linear discharge is formed by the comparator "$O-2$" (see the Fig.3).

Table 1.

$V_{in}(mV)$	$V_{in}V_{max} * 100$	$T(\mu sec)$	$T/T_{max} * 100$
25	1,0	45	1,45
50	2,0	65	1,61
100	4,0	125	4,03
200	8,0	250	8,07
300	12,0	375	12,10
400	16,0	480	15,50
500	20,0	610	19,70
750	30,0	920	29,80
1000	40,0	1260	40,70
1500	60,0	1880	60,70
2000	80,0	2450	79,20
2400	96,0	2980	96,20
2500	100,0	3100	100,0

It should be noted that this converter is nongated and, for this reason, so there appears a methodical error because the during first cycle there is integrated an algebraic sum of the input current i_{in} and the reference current i_o .This methodical error of "$q \to t$" - transformation is equal:

$$\delta = t_{up}/(T - t_{up}) \approx t_{up}/T \tag{8}$$

Since this error depends on the ratio t_{up}/T it can be made as a very small as possible at the condition $t_{up} \ll T$ (this error can be avoid if the output voltage Vout will be controlled by the comparator "$O - 2$").

The real dynamic range, $D = T_{max}/T_{min}$, of this converter is twice more than the dynamic range of the up/down integrator with switches at the condition that $V_z = 2V_{out.m.}$.

In Table 1 there is given the dependence of there time interval T on the input voltage V_{in} by the constant duration of the input signal $t_{up} = t_2 - t_1 = 10\mu sec$. The relative methodical error where will be: $\delta_{min} = t_{up} * 100/(T_{max} - t_{up}) = 10 * 100/(3100 - 10) \approx 0,3\%$.

2.3. Multichannel charge-to-digital processor with $10^5 : 1$ *dynamic range.*

Basic idea of the analog processor is to generate pulses width proportional to the input pulses charges (see Fig4). For this reason in the capacity of the units CONV there are used charge - to - time converters (CTCs) [5]. With this end a view incoming charges at first are integrated by the Miller's integrators (G). Each of the electronic channels contains three such parallel integrators with the different voltage gains: G_1, G_2 and G_3 on condition that $G_1 > G_2 > G_3$. Therefore a small signals are amplified more than large ones, so there is a smoothing out effect. Thus, the total dynamic range of a $5 \times 10^5 : 1$ was covered.

The maximum code N_m of all output codes is required to be submitted to $N_m < N_c$, where N_c is digital word of the counters C (see the Fig.4).

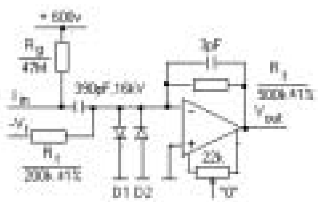

Fig.1

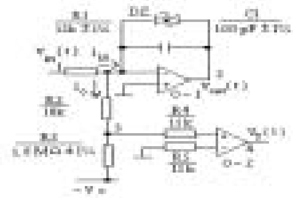

Fig.2

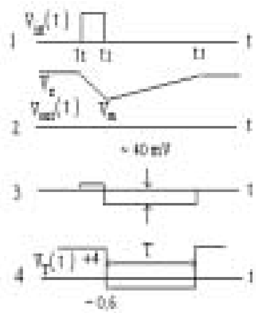

Fig.3

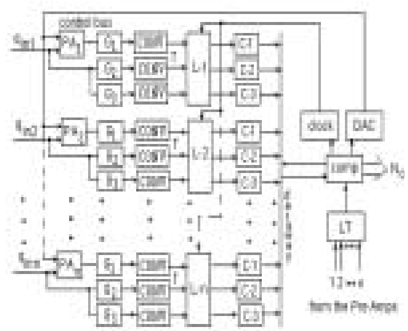

Fig.4

Fig. 1.

The automatic correction of the errors of the incoming charges conversion to the output digital data (calibration control) is realized by the 12-bit DAC in the feedback loop from the computer to the input processor. The algorithm of the automatic correction of the errors at present is developed on the basis of the iterations‘ method.

3. Conclusions

The hadron calorimeter wide dynamic range ($5 \times 10^5 : 1$) multichannel electronics for experiments in cosmic rays is described.

The analogue circuits (preamplifiers and charge-to-time converters) are built as a separate analogue cards (board dimensions are $160 \times 100mm$). Electromagnetic interference is avoided by a careful layout: on the ionization chambers there were placed the analogue cards only, the digital units were placed on the CAMAC crates and the copper screens were used. The future efforts have to be oriented to implement more simple processor allowing the design of a monolithic or hybrid electronic channels.

4. References

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